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Raindrops and Erosion

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Current popular articles have created the impression that the raindrops are principally or solely responsible for our serious water-erosion problems and that these problems can be solved by intercepting this agent of soil damage.

Although the effect of raindrops falling on the soil has been recognized for many years as a factor in the erosion process, it has been scientifically determined that it is but one of several important causal factors involved in the process of erosion.

This circular shows the relation of raindrops to the erosion process. Also, it brings into proper perspective other forces responsible for erosion by rainfall.

NATURE OF EROSION

The gradual wearing down of the earth's surface by processes of rock decay (rock weathering), combined with the action of water, wind, ice, and gravity and with the varied effects of plants and microscopic organisms, under undisturbed natural conditions, is frequently referred to as a normal geologic process—the process of leveling off of the earth's surface. The normal erosion accompanying this process of earth planation is commonly called natural or geologic erosion (fig. 1).

Man has had little or nothing to do with this age-old type of erosion, even though it has to a very considerable degree been responsible for shaping the configuration of many of the world's mountains, plateaus, valleys, and canyons. This slow process has been responsible, also, for building alluvial plains and many of the important sand-dune areas of the world.

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FIGURE 1.—Man has had little to do with the natural processes by which rainfall and runoff through the ages have produced the erosional landscape.

Geologic erosion takes place at the leisurely pace of millenia. The action of wind and water, aided by freezing, thawing, solution, and gravitational creep, is the principal agency in this type of erosion.

Among man's actions which contribute most to soil erosion is the removal of nature's protective cover of vegetation, followed by wasteful methods of plowing and grazing the bared surface. Soil eroded from the upper part of sloping areas is often deposited over lower slopes and in stream bottoms. Over a period of time this results in enormous losses of eroded soil. Moreover, it results in the filling (siltation) of streams, reservoirs, and harbors with the products of erosion. It also results in accelerated flood damage.

Most of the erosion caused by water in the humid areas has its origin in rain and snow. Rainfall varies widely over the world in amounts, frequencies, and intensities; and the relative amount of erosion that takes place is directly related to these local variations, where the land conditions and cover values are similar.

Soil erosion by water is a physical process requiring force to move the soil. The force necessary to cause erosion on nonirrigated areas comes from rains, melting snow, and runoff. The amount of rainfall, the force of rainfall impact, and the rate of runoff greatly affect rates of soil removal. Some soils are much more absorptive than others and, therefore, more resistant to erosion.

In this and other ways, the degree and extent of erosion will depend on the ability of the soil to withstand the abrasion, splashing, lifting, and transporting forces of water and wind.

In order to understand the erosion process and evaluate the several factors entering into it, each of these factors must be analyzed and understood. The quantity of soil removed by erosion by a single rainstorm will depend on the kind of soil, the slope, the amount and kind of cover, and the intensity and duration of the rainfall.

Under natural conditions, the wearing away of the land surface by the combined forces of running water, wind, gravity, waves, and moving ice has generally been considered a normal geological process. Failure to distinguish between the timeless process of *normal erosion* and the rapid action of *accelerated erosion*, resulting from human disturbance of the natural conditions of the land surface, explains in large degree the general failure to recognize the vast difference in the effects of these contrasting types of soil disturbance and removal. In no small measure this failure to differentiate between (a) normal erosion, under which soil is built up and maintained in favorable condition for the growth of plants, and (b) accelerated erosion, under which soil is rapidly impoverished or wasted, undoubtedly accounts for much of the indifference that prevailed so long with respect to land depreciation under human occupancy.

In its broadest sense geologic erosion, or natural erosion, represents the erosion characteristic of the land in its natural environment, undisturbed by human activity. It is a continual process of surface planation, a normal geological activity, which, across the ages, has contributed to the sculpturing of numerous mountains, plateaus, valleys, canyons, plains, and mesas and to the building of alluvial plains and deltas, coastal plains, lacustrine beds and terraces, submerged continental shelves, high piedmont plains, valley fills, aeolian deposits, alluvial cones and fans, and colluvial aprons.

Normal erosion, assisted by the complex process of rock weathering, aids both in the formation of soil and in its long-time distribution from place to place. It occurs in a natural, undisturbed environment, where vegetation, with its canopy, stems, ground cover of vegetative litter, and underground network of binding roots, together with the absorptive, stable character of normal, humus-bound soil, probably retards the transposition of surface soil by rain, wind, and gravitational movement to a pace no faster, generally, than the pace at which new soil is formed from parent materials beneath.

Under the impact of forces associated with the natural soil environment—the collective influence of vegetation, micro-organisms, climate, and corollary physical and chemical activities—the soil is so processed, normally, as to establish within its mass characteristics that give it marked resistance to surface removal. Spongelike and granular, topsoil absorbs rainfall at a relatively rapid rate. Hidden conduits—root holes and the tunnels of insects, earthworms, and rodents—perforating both surface and subsurface layers carry water deep into the substrata. Infiltration is further assisted by such structural openings as the soil pores, cracks, cleavages, or fractures that often puncture the profiles of normally developed soils.

Erosion, normally proceeding under a protective cover of vegetation, goes on so slowly that it probably is beneficial as a rule, seldom harmful in effect. Without it there would be, undoubtedly, much more severely leached land, more waterlogging of land, and more land with unfavorable hardpan or claypan in the subsoil.

That phase of surface wearage having to do with the abrasion of consolidated rocks on which there is little or no soil may be called *rock erosion* and can be ascribed to the process of normal or geologic erosion. Such activity is the principal contributor to the development of rock gorges and badlands.

The vastly accelerated process of soil removal brought about by human interference with the normal equilibrium between soil building and soil removal is designated *soil erosion* or *accelerated erosion* (fig. 2).

Under the artificially created conditions resulting from the removal of the protective cover of vegetation in order to cultivate or pasture the land, soil is displaced bodily much faster than it can be formed. Unless adequate measures are taken to guard against such abnormal acceleration of soil removal, it becomes the most potent single factor contributing to the deterioration of productive land.

Normally, erosion by water proceeds on a surface stripped of its cover of vegetation and vegetative litter (whether by ax, plow, grazing, fire, invasion of rodents, or whatever cause) at an increasing rate as the upper, more absorptive layers of soil are successively removed. As pointed out, the humus-charged, granular topsoil is generally more resistant to erosion than the less absorptive, less stable, humus-deficient layers beneath. It is permeated with millions of structural air spaces

FIGURE 2.—Soil removal goes on at an accelerated rate when water is allowed to flow across fields which have been stripped of their vegetal cover.

and with openings produced by decaying plant roots, burrowing earthworms, insects, larger animals, and the fracturing caused by shrinkage on drying. The combined effects of the spongelike organic matter and the activities of micro-organisms feeding on this organic material tend to keep the surface layer granular, absorptive, and cohesive.

Heavy rains tend to seal over the soil pores of bared fields, and the larger openings into the body of the soil are often choked with soil strained from muddy infiltration. This makes the soil less absorptive and this in turn increases the runoff and erosion. Eventually, underlying layers deficient in organic matter are exposed. With few exceptions, the exposed sublayers, whether of clay or of coarser grain, are distinctly more erodible—more susceptible to removal by either water or wind—than the topsoil. Exposed clay subsoil often absorbs water so slowly that heavy rains produce rapid runoff and thus further speed the rate of erosion by abrasion. Runoff water concentrates in greater volume and moves with mounting speed and erosive effect as gullies are cut deeper into the body of the earth.

In this manner, erosion, biting into the land, proceeds by a vicious process toward impoverished soil, land ruin or abandonment, disintegration of rural communities, decline of nations.

Water and wind are the active forces of soil erosion, differing in the nature of their action and in outward manifestation but having similar action effects in the sense that both pick up and transport soil. With respect to transporting capacity, the efficiency of both agencies is greatly increased with increase in velocity. Both present major problems having to do with land defense and preservation, and the basic essential of the control methods for both is to reduce the erosive effect by slowing the rate of runoff or velocity of the wind with obstructions across their respective lines of travel. A fundamental difference is that slope is essential to erosion by water, whereas slope has no direct causal effect on erosion by wind.

Water erosion is the transposition of soil by rain water, including melted snow, running rapidly over exposed land surfaces. It is conditioned by factors of slope, kind of soil, condition of soil, land use, and amount and intensity of rainfall, and is confined to sloping areas. It is a progressive process intensified by degree of slope and condition of the land and is aggravated by cultivation, by overgrazing, and sometimes by burning and the activities of rodents. In general, it may be broadly defined under three major types which, although closely related, are by no means mutually exclusive. Two or more of them may occur simultaneously in the same field; one may develop into another. But for the purposes of discussion, the general activity of water erosion may conveniently be subdivided into sheet erosion, rill erosion, and gully erosion.

Sheet washing is the more or less even removal of soil in thin layers over an entire field. It is the least conspicuous and the most insidious type of erosion.

Unprotected land varies widely in its susceptibility to *sheet* washing, the differences depending principally on topographic features, climatic environment, and the character of the soil. Steep and fairly steep lands and those subjected to heavy or intense rainfall are most

FIGURE 3.—Water running off unprotected sloping lands tends to concentrate in streamlets. The resulting rill erosion is characterized by small but well-defined incisions in the land surface.

likely to encounter serious erosion difficulties. But the vulnerability of any field or pasture to sheet washing is conditioned to an important degree on the inherent erodibility of the soil itself. Areas where a loose, shallow layer of surface soil overlies a dense subsoil of low permeability are peculiarly susceptible to this less noticeable form of water erosion. It is also likely to prevail on soils of high silt content, fragile sandy soils, and all soils deficient in organic matter. Actually, sheet erosion takes place to some extent wherever water flows across unprotected sloping land, as evidenced by the fact that runoff from such areas is always muddied, in some degree, with the products of erosion—soil in suspension—and is never as clear as runoff from wooded and grass-covered areas.

Similarly, nearly all bare areas are subject to wind erosion when dry, particularly where the soil has been loosened by cultivation. A fundamental difference of some importance is that when soil is removed from a field by water, the same agency cannot re-transport any of it to the place of origin, as sometimes happens under the impact of shifting winds.

Sheet washing proceeds so slowly, as a rule, that farmers often fail to notice its effects or even to realize the cause of the color changes from dark to light taking place in their sloping fields as the darker surface soil is gradually washed off to lighter colored subsoil. They sometimes fail, also, to understand the appearance and expansion of spots of relatively unproductive subsoil or bedrock similarly exposed by slowly progressive sheet erosion.

Sheet erosion grades so imperceptibly into *rill erosion* that the two cannot everywhere be sharply differentiated. Some grooving of the soil goes on in connection with much or most of the erosion commonly assigned to the category of sheet washing; but in the broader sense, sheet erosion involves the removal of a thin sheet of soil more or less uniformly from the entire extent of an exposed area of uniform character.

Instead of flowing evenly over a sloping field, runoff water generally tends to concentrate in streamlets of sufficient volume and velocity to generate increased cutting power. The resultant rill erosion, in contrast to sheet washing, is characterized by small but well-defined incisions left in the land surface by the cutting or abrasive action of the water (fig. 3). The trenching typically is straight-lined, approximately; but frequently the incisions join in intricate crisscross patterns, as the result of deflection of the runoff by some obstacle in its path. The channel cross section is box-shaped, representing a miniature box canyon that can be produced only by the cutting effect of running water.

From the practical standpoint, *rill erosion* is that type of accelerated erosion which produces small channels that can be obliterated with ordinary methods of tillage. It is more apparent than sheet washing but almost as often neglected. The incisions are easily plowed over, so that many farmers are likely to forget them or to minimize their importance once they are smoothed out with agricultural implements.

FIGURE 4.—The sudden melting of snow under the impact of warm winds can produce severe rill erosion.

With respect to extent of damage, this form of soil removal is about as serious as sheet washing.

When slopes are smooth, runoff water ordinarily concentrates in rill-producing streamlets, usually where there is intense rainfall and a relatively small amount of percolation. Rill erosion consequently is most common in regions of rather intense precipitation and on soils of low absorptive capacity. Soils with a high silt content are especially vulnerable, although the process usually occurs during heavy rains on all areas where loose soil overlies dense subsoil. The sudden melting of snow, such as takes place in the region of the Palouse (southeastern Washington and adjacent parts of Idaho and Oregon) under the impact of warm winds from the Pacific (chinooks), produces very severe rill erosion (fig. 4). Frequently, the eroded soil is deposited on lower lying accumulations of snow to form peculiar patterns.

Gully erosion takes place either where the concentrated runoff from a slope increases sufficiently in volume and velocity to cut deep incisions (gullies) in the land surface or where the concentrated water continues cutting the same groove long enough to develop such large incisions. Usually, gullies follow sheet erosion or result from the neglect of rills. But frequently they have their beginning in slight depressions of the land surface where runoff water normally concentrates. Often they develop in natural field depressions or in ruts left by the wheels of farm machinery driven up and down hill over soft ground. They frequently form also in the trails of livestock and along furrows running up and down the slope.

Ordinarily, these erosion-produced channels carry water only during or immediately after rains or following the melting of snow. Gullies usually cannot be obliterated by normal tillage; most of them cannot be crossed by farm machinery (*2*).[1]

RAINFALL

The wide range in the amount and intensity of rainfall has much to do with the amount of runoff. Also, the degree of slope is of primary importance because of its influence on velocity of flow and rate of infiltration. It has much to do, also, with surface sealing.

Some Effects of Rain Splash

Raindrops strike the soil with considerable force. The larger ones disturb the immediate surface, especially where the soil is loose or fragile. Raindrop disturbance is most likely to be a geyserlike splashing of the wet soil, throwing particles into suspension and thus contributing muddy water—and the soil suspended in it—to the runoff (fig. 5). Dry soil resists wetting largely because of air contained in the small pores so that for a brief interval during a rainstorm only a small portion of the surface material is actually wetted. The time

[1] Italic numbers in parentheses refer to literature cited.

required for wetting depends largely on the moisture content of the soil. The drier the soil, the slower it wets.

Under the beating and splashing of rain, however, the surface soon becomes moistened, partly because of the gouging and mixing force of raindrop impact. Beneath the wetted surface layer, the soil may still contain considerable quantities of trapped (sealed-in) air which, by actually filling the openings through which it must travel, quite effectively retards downward movement of water. The surface tension of water in contact with the soil air may further resist movement downward. If merely the surface is wetted, a crust is formed which

FIGURE 5.—A splashing raindrop, greatly magnified. Raindrops strike with considerable force and cause a geyserlike splashing of the wet soil.

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on drying may become even more resistant to penetration by later rains through the process of hardening, thus increasing runoff. When conditions are such that water is readily absorbed by the soil at the beginning of a rain, small particles are carried downward by infiltration. By a process of straining out, these particles plug the soil pores, thus, later on, sealing off further penetration of water.

If the soil is dry and cloddy, capillary forces pull water into the clods, trapping and compressing considerable quantities of air. As the moisture decreases the strength of the cementation, the compressed air and unequal stresses tend to break up the clods, causing them to slack into a pasty mass. Spreading out, portions of this slacked, more or less viscous material are drawn into the spaces between the clods or soil fragments so that the surface soon becomes less permeable. If unprotected by vegetation, the surface quickly assumes a sealed condition resistant to rapid penetration of water.

The physical processes thus temporarily sealing the soil surface collectively produce much the same effect as puddling, and the result is lowered infiltration and increased runoff. Frequently, this surface layer is so impervious that the soil at a depth of an inch or two will be dry, even with rain continuing. As rain proceeds, however, the abrasive force of the increased runoff produces increased scouring (surface abrasion), which under certain conditions wears through the skinlike layer and starts trenching or rilling. Concentration in slight depressions, or as the result of deflection by obstacles in the pathway of flowing water, also produces channels or rills that serve to accelerate the erosive effect of the continuing rain.

Muddied water not only serves to clog soil openings with material filtered from the percolating suspension, thus accelerating runoff and erosion, but frequently, if not generally, such water may have a greater cutting effect than clear water, especially where the suspension carries sharp-edged mineral particles, such as sand derived from the breaking down of quartz-bearing rocks.

A raindrop has weight, of course, and so, normally picks up speed while falling, striking the ground with considerable force. This was shown by J. Otis Laws of the Soil Conservation Service in 1941 (*10*).

The total impact force of water of one heavy rain striking the ground, as calculated by Nichols and Gray (*15*), indicated that 2 inches of rain falling on 1 acre, at 20 miles an hour, would have enough energy to raise a 7-inch layer of soil to a height of 3 feet over that acre. This would not be true, however, in the case of slow or "drizzling" rains, with the water reaching the ground over a longer period. This important difference in delivery of energy might be visualized better by comparing the effect of a crushing blow with a sledge hammer to an equal amount of force delivered by many light taps with a tack hammer. In the first instance, great damage could be done even to a highly resistant body such as a rock, but in the second instance, an equal amount of force would do little or no damage to the same rock.

The total force of a rainstorm in reality is dispersed throughout the duration of the storm. Accordingly, the striking force against which land must be protected is the individual impacts of the raindrops as they fall, the smaller drops causing least disturbance.

Some recently published statements with respect to the effects of raindrop splash have left the impression that this is the most important factor having to do with the erosion process. It is an important factor, but, as already pointed out, it is only one of several factors having to do with erosion on farmlands. As a matter of fact, the cutting and abrasive effect of runoff from rains and the melting of snow are of far more importance than raindrop splash, which makes its principal contribution by hurling soil particles into suspension in the runoff. It has no effect at all on the terrific amount of erosion produced by melting snow, because raindrops are not involved with this except, of course, where rainfall occurs at practically the end of the melting of accumulated snow. And raindrop splash has little or no effect where there is a good, dense cover of vegetation, or where the ground is covered with a mulch such as that utilized on millions of acres of land cultivated according to the stubble-mulch method of farming (*7*), as illustrated in figures 6 and 7.

Raindrop splash can have relatively little effect with respect to rill erosion on smoothly harrowed land prepared, for example, for seeding small grain or grass. As a matter of fact, most of the erosion in the United States is associated with rill erosion, which is characterized by long grooves, generally box-shaped, often extending from near the top of a cultivated field down the slope to the lower side of the field. Since raindrop splash on bare ground throws the fine soil particles into suspension by the process of splash, which moves soil more or less

FIGURE 6.—Residues of vegetation are left on fields after harvest in the stubble-mulch method of farming. Such residues take the impact of falling raindrops and protect the soil against splash and rapid runoff.

equally in all directions, depending on such things as wind direction and the angle of incidence at which the drops contact the ground, mechanically the process of splash cannot account for the cutting out of these straight-lined, box-shaped grooves across slopes of great lengths.

FIGURE 7.—A dense stand of wheat or other close-growing vegetation breaks the force of falling raindrops, retains part of the water on the foliage, and greatly reduces damage to the soil by rain splash.

Raindrop Characteristics

The importance of raindrops has been recognized by scientists a great many years and many studies to determine raindrop size and velocity have been carried on.

Apparently, the size of raindrops was first measured in Germany as early as 1895. J. Wiesner, pioneering in this field, published a description of his absorbent-paper method of measuring the size of raindrops (*18*). This method, with slight modifications, has been used by a number of European investigators since that time. It consists of dusting sheets of filter paper with a water-soluble dye and exposing them to the rain for a brief interval. On striking the paper, the drops cause spots which are recorded by the dye. Large drops spatter to such extent on striking the paper that precise determination of their size is not possible.

Wiesner's interest lay primarily in the largest drops in order to refute the then popular notion that the drops of tropical rains were sometimes an inch in diameter.

P. Lenard appears to have been the first investigator to show an interest in the frequency distribution of raindrop sizes. In 1904 he published tabulations showing the frequency of occurrence of drops of different sizes in several rains (*12*).

A year after the appearance of Lenard's work, A. Defant published the results of a painstaking study of raindrop size (*5*). His measurements were more precise and revealed a decided waviness in the frequency-size curve, the most frequently occurring drops having volumes showing a tendency toward a progressively doubling of the size of the drops in the ratio pattern of 1:2:4:8. Defant reported the total number of drops in each of 29 size groups for 20 rains, and again the total number of drops in 26 size groups for 7 rains. The upper limit of drop size is not reported, but in several of the rains a sufficient number of drops fell in the largest group to indicate that large drops contributed a considerable part of the total water that fell.

In 1932, E. Niederdorfer reopened the question of size ratios in raindrops by publishing an exhaustive analysis of 8 rains in which he divided the drops into no less than 97 size groups (*16*). These measurements confirmed and amplified Defant's observations. Unfortunately, Niederdorfer reported no rainfall rates.

In 1904, Wilson A. Bentley of the Weather Bureau used the flour method of raindrop-size measurement (*3*). Raindrops were allowed to fall into a layer of loose flour, 1 inch deep and with a smooth surface, contained in a shallow tin receptacle about 4 inches in diameter. The container was generally exposed to a rain about 4 seconds. Exposures were somewhat longer when the drops fell scatteringly. The dough pellets that were invariably produced were allowed to remain in the flour until they were dry and hard before they were passed through screens for separation into size groups.

The speed of falling raindrops has been studied by several investigators in the past. Probably most of these measurements were made by P. Lenard and Wilhelm Schmidt (*17*). The velocities determined by these studies had been accepted by scientists until the more precise measurements made by Laws (*10*) in 1941 showed them to be too low.

Other early workers were interested in the effects of rainfall and rain water on the soil surface. E. Wollny, a German scientist, in 1877 described the surface sealing and crust formation that resulted from soil dispersion and clogging of pore space by rainfall on bare soil (*19*). Among the more recent workers in this field are W. C. Lowdermilk, who showed the effect of a surface mulch and muddy suspensions on infiltration (*13*): and F. L. Duley and L. L. Kelly of the Soil Conservation Service, who revealed the beneficial effects of a surface mulch on infiltration and reduction of erosion (*6*). The work of H. L. Borst and Russell Woodburn of the Soil Conservation Service confirmed the findings of Lowdermilk, Duley, and Kelly and was an additional contribution to the subject of rainfall effects on soil-erosion rates (*4*).

W. D. Ellison of the Soil Conservation Service compared erosion rates and particle sizes of eroded material from runoff resulting from high rates of rainfall on bare soil to rates and particle sizes from water flooded across the plots from the upper side and to effects of simultaneous rainfall and flooding (*8*). His data confirmed the work of Borst and Woodburn on the effect of soil splash and turbulence induced in runoff water by raindrops on erosion rates of bare soil.

S. W. Phillips and I. T. Goddard in their investigations at the Guthrie, Okla., Soil Erosion Experiment Station made an outstanding contribution to soil conservation science in 1930 by measuring the effects of forest litter on water absorption and soil loss by erosion. Bennett (*1*), after pointing out the enormous importance of vegetal ground cover in connection with soil permanency, describes some of the results of these investigations, as follows:

> The work of Phillips and Goddard at the Red Plains Erosion Experiment Station, near Guthrie, Okla., gives some conception of the true significance of ground covers. At this station the forest-litter was burned from a measured area of post-oak timber in the spring of 1930, after the area had been surrounded by a waterproof metal guard, except at the lower end, where all the runoff and washoff emptied into a tank. Another area immediately alongside the burned plot, having the same forest canopy, was similarly put under control, and left undisturbed, with its natural ground cover of leaves and twigs. In May of the same year, during a period of almost continuous rainfall, the runoff from the unburned plot was at the rate of 250 gallons per acre, while the runoff from the burned plot, having the same soil and slope, was at the rate of 27,600 gallons per acre. The excess of runoff from the burned area over that from the unburned area, plus the water-holding capacity of the leaf-litter covering the latter site [the cover of leaf-litter and mold was found to have a water-absorption capacity of 33,331 pounds, or 16.7 tons, per acre] was approximately 90 tons per acre. The runoff from the former area was essentially clear, while that from the burned-over ground was muddied with the products of erosion. Thus, the effectiveness of a thin cover of leaves as a protector of the soil is seen to be far greater than commonly has been supposed, and, as Lowdermilk has recently pointed out, the chief function of such a ground cover is not merely to absorb water, but to send down clear water into the soil, rather than muddy water such as fills up and chokes the pore spaces developed through normal processes of soil building (as holes formed by decaying roots, insects and worms, and the natural pores that go with a mellow, humus-charged soil).
>
> The losses from these plots for the 2 years 1930 and 1931 (averaged) have been: for the unburned plot, 0.08 percent of the total precipitation and 0.01 ton of soil per acre; from the burned plot, 2.43 percent of the precipitation and 0.15 ton of soil per acre.

H. H. Bennett in his treatise "Soil Conservation" clearly describes the importance of the raindrop as a factor in soil erosion (*2*).

In the studies of J. Otis Laws (*9*, *10*), and Laws and Parsons (*11*), the techniques used were basically the same as the flour method described by Bentley for determining raindrop sizes and the drop-size distribution patterns for both artificial and natural rainfall, as well as a new high-speed photographic method for measuring the speed of the falling raindrops.

From these studies the size and shape of raindrops were affirmed. High-speed photographs of falling raindrops showed the drops to be flattened on the bottom, with domelike tops.

As a result of the work of Laws and his associates, the top speed of raindrops as earlier determined by Lenard and Schmidt, and accepted by scientists for over 30 years, was shown to be too low, and new and more exact speed data were thus made available. With speed and size of drops known, impact energy of each drop can be calculated with accuracy for falling drops where wind is not a factor. The relation of raindrop size to striking force and speed of fall with different heights of fall is illustrated in figure 8.

In natural rainstorms the raindrops are often driven by high winds at speeds in excess of the natural terminal velocity of the unassisted raindrop, and thus greatly add to its force of impact.

The most interesting feature of all the studies made by Laws was the high-speed motion pictures of raindrops falling into dry soil, wet soil, and soil with a shallow layer of water covering it. By means of

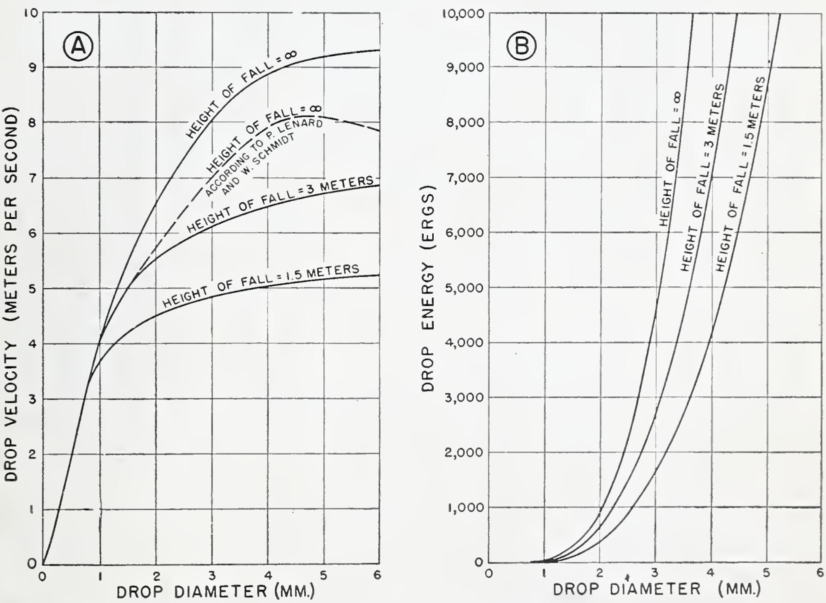

FIGURE 8.—Relation of raindrop size to striking force and speed of fall with different heights of fall: *A*, Effect on velocity; *B*, effect on impact energy.

these pictures, each drop could be observed in clear detail at any point in its descent.

The drops were shown to shatter on impact, and small soil particles were carried out with the splashing droplets. Soil particles were observed flying at times to a height of 2 or more feet and 2 to 3 feet laterally.

When the drops fall into thin layers of water over the soil surface the turbulent action of water rushing back into the area where the drop

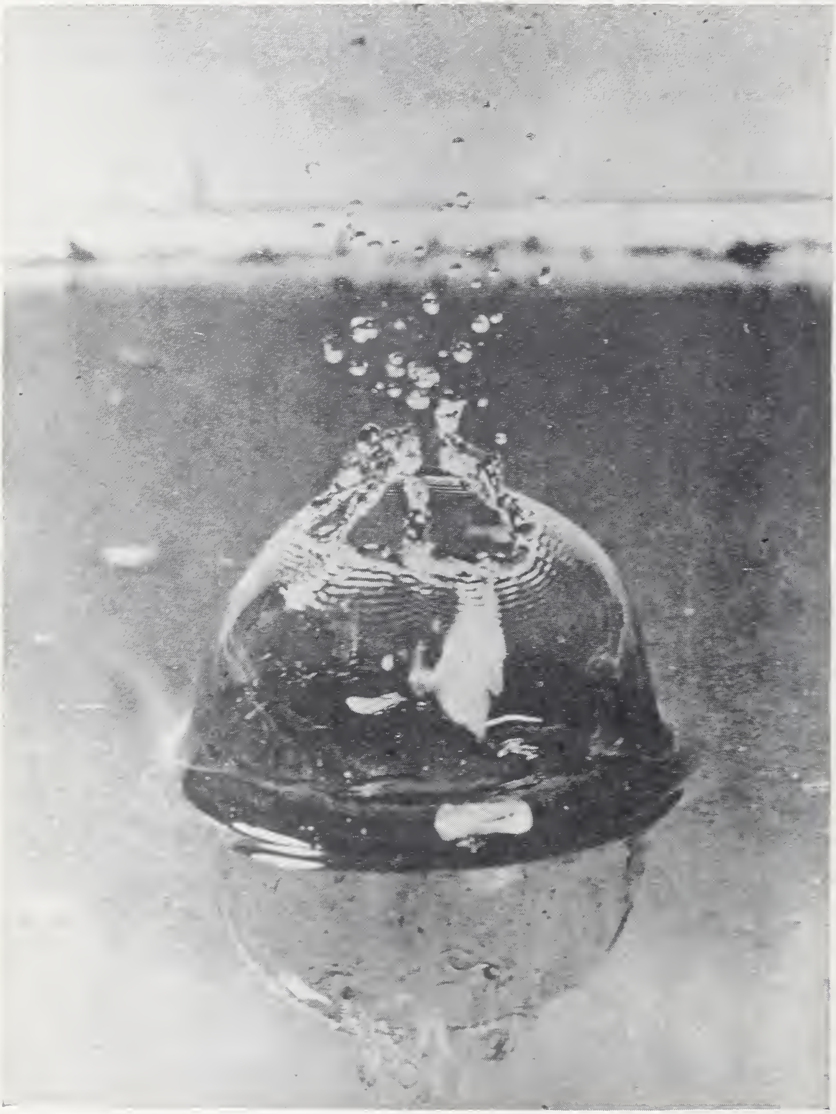

FIGURE 9.—Here a raindrop, highly magnified, has fallen into a layer of water on the soil surface. The splash throws particles of soil into suspension and thus contributes muddy water to the runoff.

fell to replace the water splashed out is of particular interest, as it was clearly seen to be moving particles of the surface soil, throwing them into suspension, thus muddying the surface water layer (fig. 9).

From these pictures it was easy to see that the splashing effect of large raindrops is accountable for a significant portion of the soil put into suspension in ready form for removal in the runoff. The effect of drop size on erosion is shown diagrammatically in figure 10. Where there is enough water for runoff, the splashing and muddying effects of raindrops account for much of the soil removed by erosion.

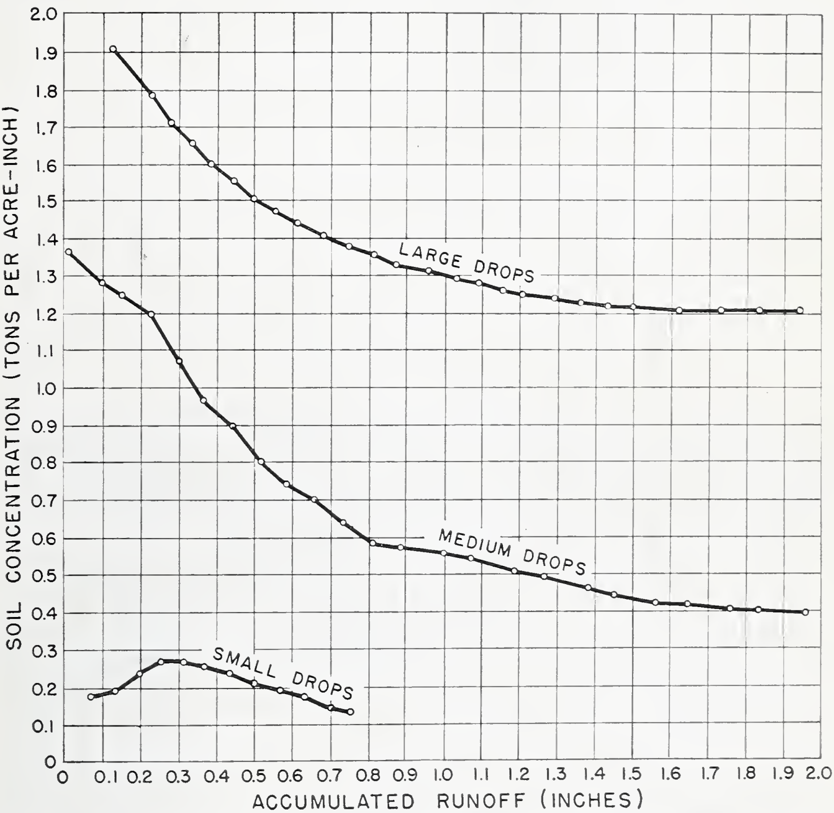

FIGURE 10.—Effect of drop size on erosion, showing concentration of soil in the runoff from similar plots subjected to artificial rains of approximately equal intensity (3.5 inches per hour).

CHANGES IN SOIL POROSITY WITH WETTING

As already pointed out, different soils vary widely in their structural and textural characteristics and also in the degree to which structural changes may take place within the soil. Little change can be expected in a single-grain structural form of sands, but in finer textured, flocculated, or granular soils wide structural changes are common.

In view of the varying rates at which soils receive and take up water, the size of pores and the number of pores of given sizes in a given soil are of great importance. If the soil has a sufficient number of pores large enough for noncapillary movement of water, the water intake and permeability will be high. If the major pore spaces are of capillary size, water movement will be relatively slow. How long a soil of high porosity will remain that way under wetting varies with the durability (rate of breakdown) of the aggregates or granules that create porosity.

It is common knowledge and may be readily observed that freshly cultivated fields have open, porous surfaces made up mainly of soil fragments and lumps of various sizes and shapes. Soils in such condition have large noncapillary pore space (fig. 11). Musgrave and Free of the Soil Conservation Service showed, in 1936, that this greatly enhances the intake of water (*14*).

When lumps or fragments of such freshly cultivated soil are wetted, either by rain or irrigation water, important changes occur. The slaking effect of air trapped in the pores, already pointed out, and the consequent dispersion, or disintegration, of the wetted soil aggregates and lumps cause the soil to "melt," or run together, into various degrees of consolidation, and, in some instances, into a completely deflocculated or "pasty," viscous condition. The water-intake capacity, which is determined largely by the noncapillary pores prior to or during the early stages of wetting, changes with the degree of soil

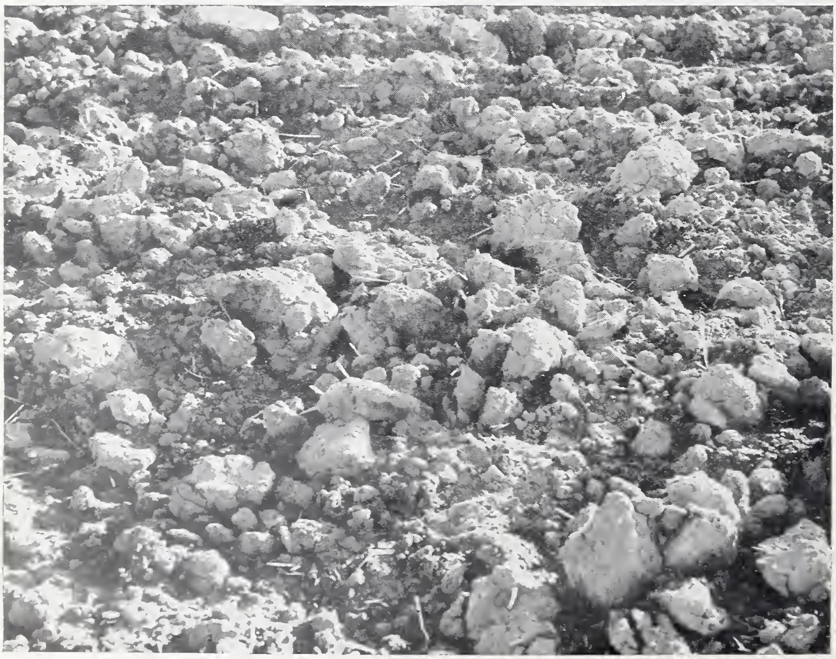

FIGURE 11.—Earth clods on the surface of a freshly cultivated field. The large open pore spaces greatly enhance the intake of water.

dispersion, or breakdown of the aggregates, into capillary movement, and this greatly reduces the rate of infiltration, causing a corresponding increase in runoff. The pore spaces available for water intake are normally of more durable nature in unplowed soil than are the temporary pores created by tillage fragmentation, and the soil aggregates and channels of worms, insects, etc. are not so subject to rapid breakdown. Consequently, initial infiltration rates hold up well for long periods of wetting under this more nearly natural condition.

Raindrop impact on bare soil, especially where freshly cultivated, hastens the breakdown of soil aggregates, thus aiding in throwing soil particles into suspension ready to be carried down into the soil pores or moved off in the runoff. But the effect of soil slaking and soil dispersion when the material is wetted also affects pore size, inflltration rate, runoff, and erosion.

RUNOFF

The force of running water is dependent on volume and rate of flow. As rain water in excess of that which soaks into the ground accumulates, runoff begins if the ground surface is sloping. Much of the soil removed, especially in the early stages of off-flowage, consists of small particles carried in suspension. Later, if the rain continues, coarser particles are floated off, as the hydraulic force increases with increased volume of water. Also, fragments of organic material are picked up from the surface of the ground and floated off.

With splashing effect of raindrops, there is a tendency, especially in fields and on bare ground, for the runoff to float away relatively more of the finer, lighter particles, including some organic matter, than of the coarser, heavier particles. This assorting effect, amounting to a process of elutriation, tends sometimes to leave, even on gentle slopes, a thin covering of sand or small pebbles (often of a conspicuous light color) where the material formerly was a sandy loam or loamy sand. This normally goes on with sheet erosion. But sheet erosion often or usually passes into rill erosion, or a combination of both.

As runoff water concentrates in volume and velocity it tends to assume turbulent channelized flow with high erosive power. The hydraulic force exerted by such turbulent flows is a primary factor in soil erosion, especially gully erosion. The power of such flow enables the runoff water to tear loose, chiefly by abrasion, and remove even coarse gravel and stones, thus cutting deep trenches into the surface of the land. Gullies typically are formed by channelized flow; many millions of acres have been ruined for any further immediate cultivation in the United States by this violent form of erosion. Much additional damage results from the deposition over lower, less sloping land of outwash of sand, gravel, and sometimes boulders.

Thus, it is seen that at least three major forces are involved with the process of soil erosion by water: (1) Transportation, (2) abrasion by running water, and (3) dislodgment (and throwing into suspension) of soil particles by raindrop splash.

None of these forces exerts any important effect on level land in the way of soil removal. On such areas the most difficult problem often is managing the waterlogging effects of rains—getting rid of excess water.

While important physical changes in the surface soil itself are brought about by raindrop splash, such as loosening of the soil and throwing it for short distances, more or less equally in all directions, depending on wind and the incidence of contact, actually little soil is removed from a field by this process acting alone.

This does not in any sense mean that raindrops are not an important factor in the erosion process. It has been demonstrated by Laws, Borst and Woodburn, Duley, and others that raindrop splash is capable of putting much fine soil material into suspension in runoff. This, as already pointed out, is especially true of soil loosened by tillage operations. After all, it is flowing water that carries soil bodily out of unprotected sloping fields and overgrazed pastures. Without runoff there will be no appreciable soil removal from an area by the erosion process, except through the action of wind.

Runoff seldom approaches 100 percent of the rainfall. Twenty-five to thirty percent, or more, of the precipitation is considered a serious rate of runoff for any rain. However, much of this water soon concentrates into channelized flow where erosion damage of great magnitude results. It is this massing and concentration of force that gives runoff water its ability to produce such serious damage in the form of rills and gullying.

That soil erosion by water can result from runoff water only, and without the aid of raindrop splash, is demonstrated by the deep rilling and heavy soil losses suffered on the Palouse wheat fields of the Northwest from snow melt. Recent field studies of rill erosion produced by melting snow show that as much as 150 tons of soil per acre have been removed in 3 to 4 days of snow melt.[2]

Tens of thousands of soil and water measurements have been made at the Erosion Experiment Stations established under the Buchanan Amendment in 1929 and subsequently. Many thousands of additional measurements have been made at other stations and in field studies by the technicians of the Soil Conservation Service and its cooperators. There have been few instances of heavy soil losses in the absence of rill formation on these numerous plots and testing areas. In observations of soil-erosion effects from heavy rain on unprotected fields the severity of erosion can frequently be determined with a fair degree of accuracy at a glance by the presence or absence of rills.

PROTECTIVE MEASURES

In its program of soil conservation, the Soil Conservation Service treats the land within its capability and according to its condition through the use of adaptable conservation measures and combinations of mutually supporting measures. This entails full consideration of every controllable factor having to do with the erosion process.

For protection of land from damaging effects of raindrop splash the most practical measures are close-growing cover crops, stubble mulching, and surface application of such organic materials as manure, sawdust, woodchips, or rotten hay. These thick-growing crops and surface mulches serve to break contact between raindrops and the

[2] SIDDOWAY, F. H. ANNUAL PROGRESS REPORT FOR 1950. Soil Conserv. Serv.-Idaho Agr. Expt. Sta. cooperative project, St. Anthony, Idaho. (Unpublished).

ground surface, allowing the rain to contact the ground by filtering as clear, nonturbulent water in optimum condition for rapid infiltration. The larger drops, it is important to note, for the most part are shattered by contact with the covering plant material into more or less harmless droplets or spray without much energy.

For protection from rainfall in excess of the infiltration rate of a given type of land, methods for controlling both the concentration of large volumes of water and the speed of off-flow may be necessary. Here again, as in the protection from raindrop impact, many practices and combinations of practices are available. These practices, instead of being dependent on organic materials, may be mechanical to a very considerable degree.

To be completely protected the land must have a well-planned and properly installed water-disposal system, which will safely remove all excess water with the least possible damage to the land. For the tilled land the water is placed under control where it falls by contour tillage, controlled-grade ridged rows, strip-cropping systems, terraces, and sodded waterways (fig. 12). Each of these practices has a basic purpose and capacity limitations, so that skillful combinations are often necessary properly to carry out the entire water-disposal plan.

The contoured ridges may have small capacity for carrying heavy rainfall, and must empty into sodded waterways or terraces before their capacity is exceeded. Strip cropping can effectively retard velocity of flow and cause much of the soil in the water to settle out.

FIGURE 12.—Strip cropping in support of contouring is frequently used to help control erosion on tilled land.

Where the slope is too long, the volume of water may accumulate until the barrier strips become relatively ineffective, unless terraces are used in conjunction with the strips.

Terraces are of greatest value on sloping lands, as they confine the length-of-slope effect to the width of the computed terrace interval. Graded terraces lead the intercepted water out of the field at controlled nonerosive volume and velocity, and deliver it safely to sodded waterways. Waterways and terrace outlets have the capacity to carry water downslope at much greater volume and speed than the cultivated parts of the terrace channels, because of their vegetative protection or, in some instances, linings of permanent material.

In developing erosion control, each practice should accomplish a basic objective and, if possible, contribute to others. The ideal practices are those which lend support to one another, thus providing greater protection than can be had with single practices functioning alone. However, these combinations are not always possible in practice, so that occasionally certain aspects of one practice may not contribute to the function of another. Terracing, for instance, which decreases the effect of length of slope in relation to runoff, actually increases the degree of slope on the downhill sides of the terrace ridges. This and high construction costs are the principal reasons why graded terraces usually are not planned for extremely steep land. Bench terracing is a method sometimes used in mountainous areas where steep lands must be cultivated.

One practice, used alone, seldom meets all requirements for erosion control, but it is possible to develop effective combinations of practices under most conditions. Such combinations should accomplish the following objectives:

1. *Maintain or improve soil structure, soil-water relationships, and soil productivity.* Factors commonly used for evaluating good soil conservation practices are: Organic-matter content, soil aggregation, permeability to water, pore space, and crop yield.

2. *Protect soil surface from sealing, to which raindrop impact contributes importantly.* Factors commonly used to evaluate effective surface protection are: Infiltration rates of protected versus bare soil, clearness of runoff, presence or absence of crusts on soil surface, and soil loss.

3. *Protect the soil from erosion by runoff waters.* Factors commonly used to evaluate effectiveness of water-control practices are: Presence or absence of rills and gullies, breaks in contour-tillage lines, heavy silt deposits in barrier strips, and breaks in terraces.

4. *Provide for orderly disposal of excess water during storms.* Factors commonly used in evaluating effectiveness are: Damage to terrace channels and outlets, overflow of channels, and breaks in terraces and protective linings of water channels.

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